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GROWTH AND MICROSTRUCTURAL PROPERTIES OF CADMIUM TELLURIDE THIN FILMS

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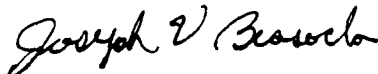
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13. ABSTRACT (Maximum 200 words) This report discusses the growth of cadmium telluride films on indium antimonide substrates. Deposition is performed using a Closed Hot Wall Epitaxy (CHWE) system. Substrate and source temperatures are shown to have pronounced effects on the growth rate and microstructure of the CdTe film and also the microstructure of the substrate.					
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EVALUATION

Cadmium Telluride/Indium Antimonide multilayer structures show promise as high electron mobility device materials for operating speeds up to 400 MHz. These two materials are promising because of their close lattice match and complimentary band structures, which in addition to high speed, offer the possibility of true three dimensional circuit development.

The study demonstrates the feasibility of growing stable cadmium telluride films on indium antimonide substrates and demonstrates the growth conditions required to ensure stable high quality films. The results of this effort will be valuable in the development of reliable device structures based on these materials.

Joseph V Bernack

Joseph V. Beasock
Project Engineer

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GROWTH AND MICROSTRUCTURAL PROPERTIES OF CADMIUM TELLURIDE THIN FILMS

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For many applications, such as IR detectors and high speed devices, we need high quality cadmium telluride (CdTe) films. To fabricate CdTe epitaxial films we are using a home-built closed hot wall epitaxy system. In this paper, we shall report the complex nature of the CdTe film's microstructure as grown on InSb substrates. Films were grown under various preparation conditions. We observe profound effects of substrate temperature and source temperature on the microstructure of CdTe films.

This study together with other properties will allow us to correlate various effects and to design an optimum preparation condition for epitaxial CdTe thin films.

An epitaxial CdTe film on different substrates is a solution to the present shortage of large area CdTe substrates.

1. INTRODUCTION

Cadmium telluride (CdTe) is widely used in X-ray and γ ray detectors because of its high atomic number. It is a suitable material for solar cells because of the optimum match of the energy gap to the solar spectrum¹. Meanwhile, it is also used as a substrate material for the epitaxial growth of $\text{Hg}_x\text{Cd}_{1-x}\text{Te}$ thin films which are extensively used as IR detectors².

The lattice constant, crystal structure and thermal expansion coefficient of InSb are very similar to those of CdTe. These properties and the large difference in the band gap between CdTe (1.58 eV) and InSb (0.13 eV) suggest that CdTe/InSb system is a promising candidate for a high electron mobility transistor^{3,4}. A recent report⁵ shows that a two-dimensional electron gas has been observed at the CdTe-InSb interface.

In our experiment, deposition of CdTe on InSb was performed with a closed hot wall epitaxy (CHWE) system. This system combines the advantages of ultrahigh vacuum substrate transport, as well as the purity of the sources of a molecular beam epitaxy, with the near-thermal equilibrium epitaxial film growth conditions of a chemical vapor deposition system. The transport of vapor from the source to the

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substrate occurs as a result of a temperature gradient which exists between the source and the substrate.

Temperatures of the various zones of the CHWE system are controlled separately. CdTe films were deposited at different source and substrate temperatures.

2. EXPERIMENTAL PROCESS

2.1. Closed hot wall epitaxy system

HWE, a kind of thermal deposition system, was first reported by Lopez-Otero⁶. The main feature of HWE is the use of a heated line (hot wall) which serves to direct the vapor from the source to the substrate. In this manner (a) the loss of evaporating material decreases, (b) the high vapor pressure of the compound or of its different components can be maintained, and (c) the difference between the substrate and the source temperature can be reduced to a minimum which promotes epitaxial growth.

Our CHWE system does not need any compensating material, the growth chamber reaches thermodynamic equilibrium quickly, and the pressure of the growth chamber is favorable to epitaxial growth.

The CHWE system consists of two main parts, the growth system and the temperature control circuit. The growth system includes a preheat chamber, two growth chambers, substrate exchange load lock system and ultrahigh vacuum system. Figure 1 shows a schematic diagram of the growth system. The ultrahigh vacuum system is always kept at the pressure of 10^{-9} Torr. The growth temperature is controlled by using a continuous, phase shift, analog temperature controller.

2.2. Substrate preparation

In the studies of the epitaxial growth of CdTe thin films, the substrate surface is of critical importance because the surface plays a major role in the nucleation and growth processes. Ideally, the surface should be extremely flat, smooth, and free of

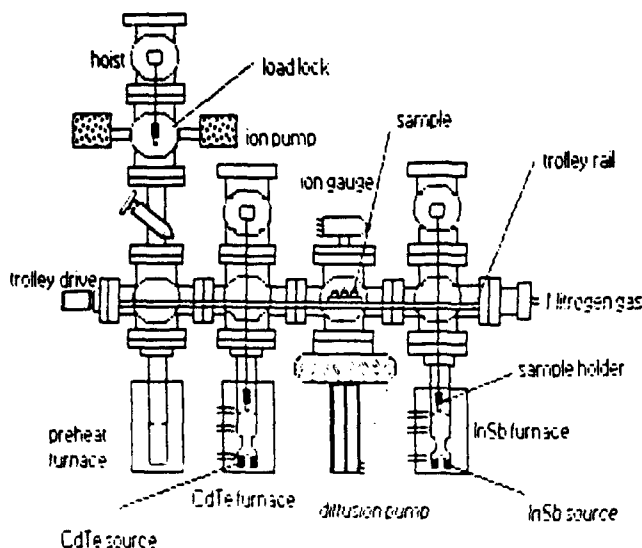


Fig. 1. Schematic representation of the CHWE system for growing CdTe films on InSb

crystalline defects. It should also be free of chemical impurities, such as oxide layers. Wood *et al.*⁷ reported that near-perfect CdTe films can be grown on InSb substrates, but the quality of these films is critically dependent on the substrate cleaning.

The substrates used are wafers of InSb(111). They are mechanically polished with 0.3 μm aluminum oxide powder and chemically etched with HNO_3 , HF and CH_3COOH solution⁸. Subsequently, a standard wafer cleaning process is applied just before they are mounted on quartz substrate holder. The surface of the InSb substrate after these processes is shown in Fig. 2. The surface of the substrate is clean and we also noticed scattered dust particles that resulted from exposing the substrate to the air.

3. RESULTS AND DISCUSSION

According to the phase diagram of CdTe for most of the temperature range the partial pressures of the two elements overlap, which is characteristic of a compound which sublimes congruently⁹. This, together with the fact that no CdTe ion was detectable using mass spectrometry and both elements have sufficient high and comparable vapor pressures^{1,10,11}, suggests that CdTe is in principle quite suitable for growth from the vapor phase⁶ using a CdTe source.

The vapors, evaporated from the source zone of the growth chamber of the CHWE, are transported along the temperature gradient and then deposited on the substrate. Therefore, the source and substrate temperatures will have a pronounced effect on the growth of CdTe thin films. Here, we shall present the effect of source and substrate temperatures on the microstructural properties of CdTe thin films.

Control of the source temperature, in order to evaporate CdTe congruently inside the CHWE chamber, is one of the main considerations in the thin film growth process. Sitter *et al.*^{9,12} reported the epitaxial growth of CdTe from a single CdTe source on BaF_2 and GaAs at source temperatures of 540°C and 495–510°C respectively. Korenstein and MacLeod¹³ used an HWE system containing CdTe powder as the source material to grow CdTe epilayers on GaAs. The source temperature was varied from 500 to 550°C.

Figure 3 shows the variation in growth rate of CdTe on InSb substrates with source temperature (475–575°C) at different substrate temperatures (280 and

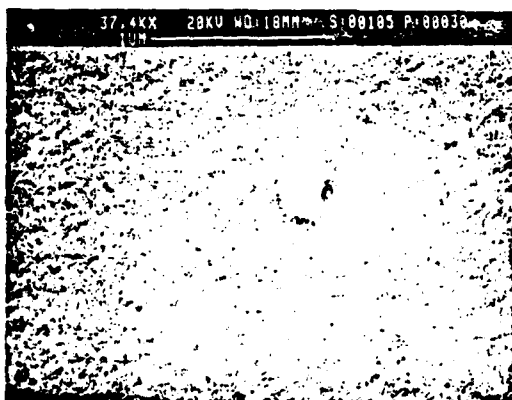


Fig. 2. The surface morphology of the InSb substrate.

It has long been understood that the quality of a thin film is highly dependent on substrate temperature. As a matter of fact, higher substrate temperatures not only change the growth rate but sometimes also change the characteristics of the substrate surface. For example, the melting point of InSb is about 525 °C and hillock formation has been observed on InSb(111) surfaces after heating of the substrate to a temperature of about 350 °C for 15 min¹⁴. In addition, the investigation of Goc *et al.*¹⁵ indicated that the sticking coefficient of tellurium is about several orders of magnitude higher than that of cadmium at a substrate temperature of 430 °C. This is because the incoming tellurium atoms substitute at the sites of outgoing antimony atoms and form thin layers of In₂Te₃¹⁶. Fontaine *et al.*¹⁷ found a steady increase in the quality of the epitaxial CdTe film with the increase in substrate temperature from 200 to 260 °C.

Therefore, to prevent unwanted effects resulting from the increase in the substrate temperature during the growth of CdTe films on InSb substrates, we kept the substrate temperature below 320 °C. The growth rates of CdTe on InSb as a function of substrate temperature at source temperatures of 475 and 500 °C are shown in Fig. 5. The growth rate increases with the increase in substrate temperature. The scanning electron microscopy pictures shown in Fig. 6 indicate that the surface morphology of CdTe films on InSb substrates is also affected by the substrate temperature. At a lower substrate temperature, because of the lower mobility of adatoms agglomerates or amorphous-like structures form, resulting in a rough surface. On the contrary, at higher substrate temperatures the re-evaporation rate increases and the generation of defects is such that the surface becomes rough again. This study indicates that an intermediate range of substrate temperatures is suitable for growing smooth CdTe films. Figure 6(b) displays the smooth surface of a CdTe film grown at a source temperature of 500 °C and a substrate temperature of 300 °C.

Source and substrate temperatures also affect the chemical and structural properties of CdTe thin films. These properties were studied by measuring the value of the full width at half-maximum (FWHM) or rocking curves¹⁸⁻²⁰.

Figure 7(a) shows the linewidths of CdTe grown on InSb(111) substrates at two different substrate temperatures. We found an increase in the linewidth with

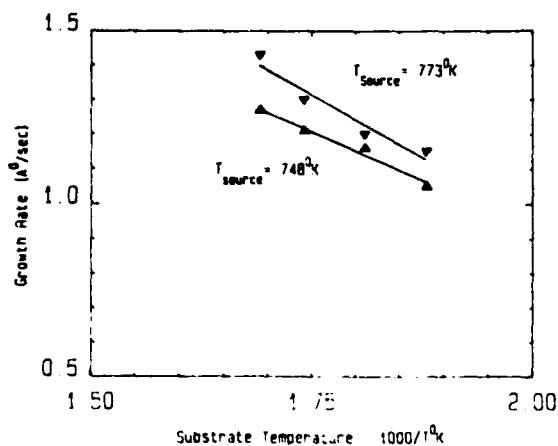


Fig. 5. The growth rate of CdTe films on InSb vs. the substrate temperature.

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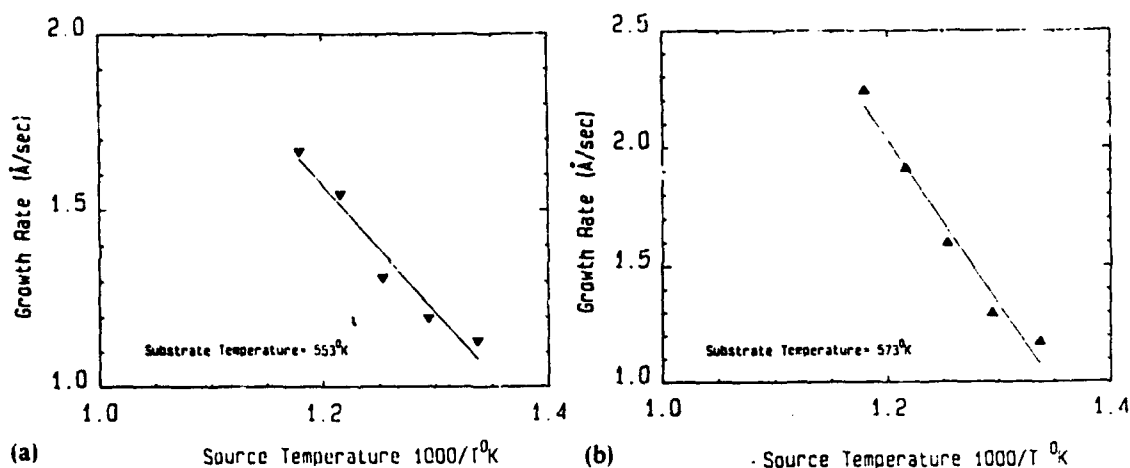


Fig. 3. The growth rate of CdTe films on InSb substrates vs. the source temperature with the substrate temperature kept at (a) 280 °C and (b) 300 °C.

300 °C). The growth rates increase linearly with the source temperature. This could be due to the increase in supersaturation ratio with the increase in the source temperature which then increases the random nucleation rate⁶, resulting in a rougher surface. As shown in Fig. 4, the surface roughness of CdTe thin films deposited at the same substrate temperature increases with the increase in source temperature.

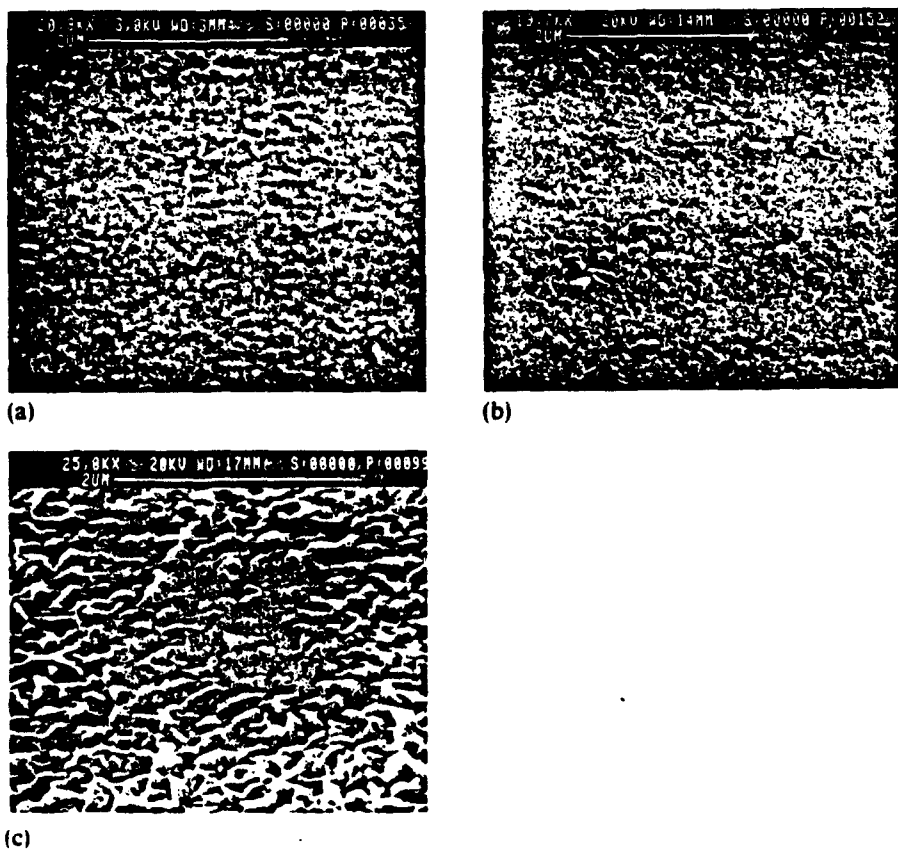


Fig. 4. The surface morphology of CdTe films on InSb substrates. The source temperatures are (a) 475 °C, (b) 550 °C and (c) 575 °C. The substrate temperature is 300 °C.

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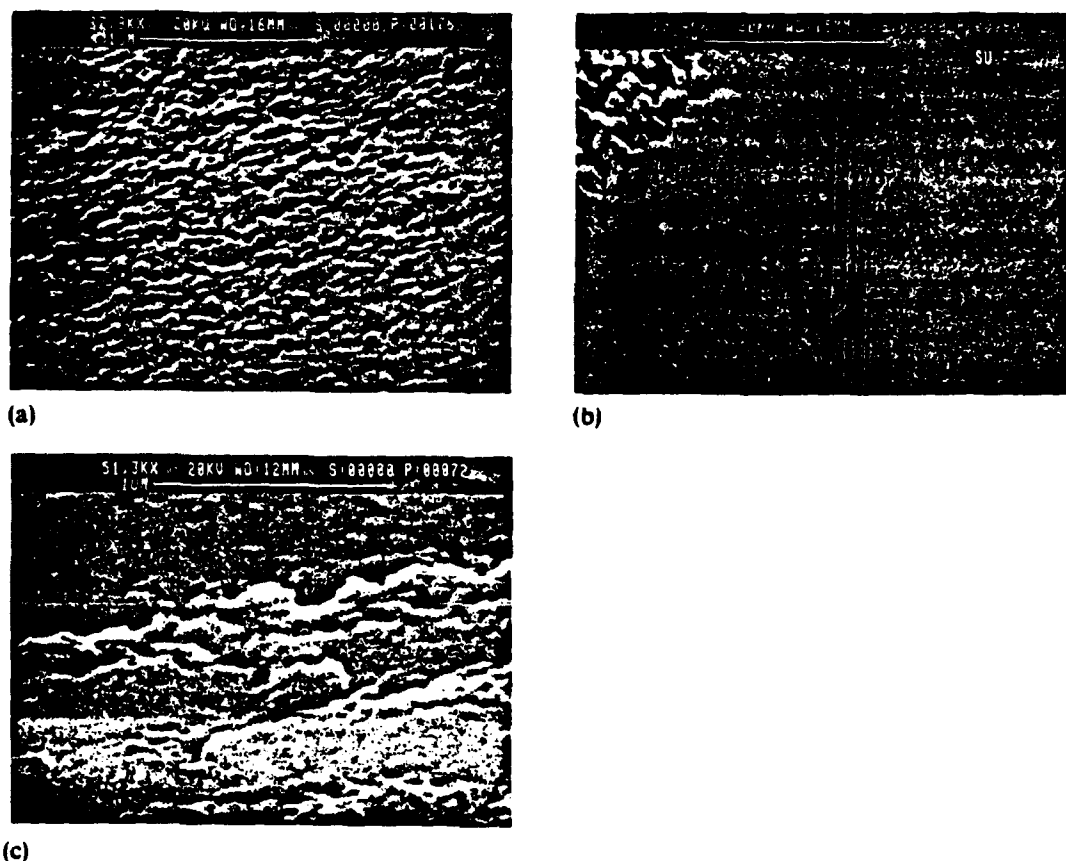


Fig. 6. The surface morphology of CdTe films on InSb. The substrate temperatures are (a) 280 °C, (b) 300 °C and (c) 320 °C. The source temperature is 500 °C.

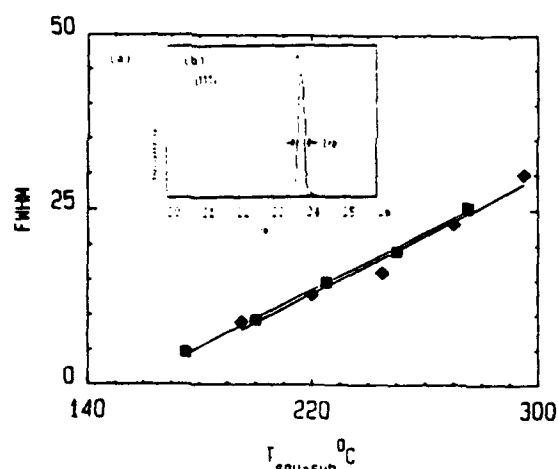


Fig. 7. (a) FWHM of (111) diffraction peaks vs. the difference between source and substrate temperatures (◆, $T_{sub} = 280$ °C; ■, $T_{sub} = 300$ °C). (b) The rocking curve of a CdTe film grown at $T_{sub} = 550$ °C and $T_{sou} = 300$ °C.

increasing difference between source and substrate temperatures. However, with the same source temperature, the (111) diffraction peak had a narrower linewidth for $T_{sub} = 300$ °C than for $T_{sub} = 280$ °C. This behavior is also seen in the CdTe microstructure (Fig. 6); the smoother surface of CdTe films has the narrower

linewidth. This indicates an improvement in crystalline property as predicted by Moazed²¹. The narrowest linewidth of CdTe on InSb is 4.61 minutes of arc at a source temperature of 475 °C, which is comparable with the result of Wood *et al.*⁷.

The rocking curve has a sharp peak and symmetrical curve, as shown in Fig. 7(b), which indicates the absence of low angle boundary characteristics of bulk CdTe material¹³. We also note from our investigation that CdTe films suffered uniform strain, as reported by Fontaine *et al.*¹⁷, from the mismatch of lattice constant and thermal expansion coefficient between CdTe and InSb.

4. CONCLUSION

CdTe films were epitaxially grown on InSb substrates using a CHWE system. Because the physical properties of both materials are so similar, smooth crystalline CdTe films on InSb have potential for many applications. We studied the effect of the source and substrate temperatures on the morphological behavior of CdTe thin films on InSb substrates. Correlating various effects, we grew good quality CdTe films with smooth surfaces at a source temperature of 500 °C and a substrate temperature of 300 °C.

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